

1           1. An apparatus for preparing a blood component for cryopreservation by  
2 mixing the blood component with a volume of cryopreservation solution that exposes  
3 the blood component to a risk of osmolarity shock, the apparatus comprising:  
4           at least one variable-speed pump coupled to the volume of cryopreservation  
5 solution and to the blood component, operation of the pump at a given speed defining a  
6 respective flow rate of cryopreservation solution to the blood component; and  
7           a controller operably coupled to the at least one pump so as to control the rate at  
8 which cryopreservation solution is delivered to the blood component, the controller  
9 configured to dynamically adjust the flow rate of the cryopreservation solution to  
10 reduce the risk of osmolarity shock to the blood component.

1           2. The apparatus of claim 1 further comprising an anti-bacterial filter disposed  
2 between the cryopreservation solution and the blood component.

1           3. The apparatus of claim 2 wherein the controller dynamically adjusts the  
2 cryopreservation flow rate so as to maintain a substantially linear increase of blood  
3 component osmolarity.

1           4. The apparatus of claim 3 wherein the controller is further configured to  
2 determine repeatedly the amount of cryopreservation solution added to the blood  
3 component, calculate a new flow rate based on the determined amount of

4 cryopreservation solution and adjust the at least one pump to deliver cryopreservation  
5 solution at the new flow rate.

1 5. The apparatus of claim 4 wherein the controller determines the amount of  
2 cryopreservation solution, calculates the new flow rate and adjusts the at least one  
3 pump on a real time basis.

1 6. The apparatus of claim 5 wherein the controller is further configured to  
2 determine a requisite volume of cryopreservation solution to achieve a desired  
3 cryopreservative concentration within the blood component.

1 7. The apparatus of claim 6 wherein a tube connects the cryopreservation  
2 solution to the blood component and a pressure probe is disposed in the tube  
3 downstream of the at the least one pump, the pressure probe providing a corresponding  
4 pressure signal to the controller which is further configured to de-activate the at least  
5 one pump if the pressure signal exceeds a pre-determined threshold.

1 8. The apparatus of claim 1 wherein the blood component is red blood cells and  
2 the controller is configured to adjust the speed of the at least one pump so that the flow  
3 rate of cryopreservation solution is substantially given by the following equation:

$$4 \quad K [V_i * (W * Hct_i / 100) + V_g]^2 / [V_i * (W * Hct_i / 100) * (O_i - O_g)]$$

5 where,

K is the selected rate of increase in osmolarity of the red blood cells,

$V_i$  is the volume of red blood cells,

W is the volumetric percentage of water in the red blood cells,

$Hct_i$  is the hematocrit level of the red blood cells before cryopreservation.

$V_g$  is the volume of cryopreservation solution that has already been added to the red blood cells prior to the current flow rate calculation,

$O_i$  is the osmolarity of the red blood cells before cryopreservation, and

$O_g$  is the osmolarity of the cryopreservation solution.

9. The apparatus of claim 8 wherein the controller is configured to initially adjust the speed of the at least one pump so that the initial flow rate of cryopreservation solution is substantially given by the following equation:

$$K * V_i * (W * Hct_i / 100) / (O_i - O_g).$$

10. The apparatus of claim 9 wherein the controller is further configured to determine the volume of red blood cells,  $V_i$ , substantially in accordance with the following equation:

$$NW_i / [1.1 * Hct_i / 100 + 1.026 * (1 - Hct_i / 100)]$$

where,

$NW_i$  is the net weight of the red blood cells prior to cryopreservation.

11. The apparatus of claim 10 further comprising a shaker platform for agitating the blood component as the cryopreservation solution is being delivered thereto.

1           12. The apparatus of claim 1 further comprising a shaker platform for agitating  
2 the blood component as the cryopreservation solution is being delivered thereto.

1           13. The apparatus of claim 2 wherein the anti-bacterial filter has an operating  
2 pressure range and the controller is further configured to prevent the pressure of  
3 cryopreservation solution at the anti-bacterial filter from exceeding the operating range.

1           14. A method for preparing a blood component for cryopreservation by mixing  
2 the blood component with a volume of cryopreservation solution that exposes the blood  
3 component to a risk of osmolarity shock, the method comprising the steps of:

4           determining the volume of cryopreservation solution needed to obtain a desired  
5 concentration of cryopreservative within the blood component;

6           coupling the volume of cryopreservation solution to the blood component by  
7 means of at least one variable-speed pump such that operation of the pump at a given  
8 speed defines a respective flow rate of cryopreservation solution to the blood  
9 component; and

10          dynamically adjusting the flow rate of the cryopreservation solution by  
11 periodically changing the speed of the at least one pump to reduce the risk of osmolarity  
12 shock to the blood component.

15. The method of claim 14 wherein the step of dynamically adjusting comprises the step of changing the speed of the at least one pump so that the flow rate of cryopreservation solution is substantially given by the following equation:

$$K [V_i * (W * Hct_i / 100) + V_g]^2 / [V_i * (W * Hct_i / 100) * (O_i - O_g)]$$

where,

K is the selected rate of increase in osmolarity of the red blood cells,

$V_i$  is the volume of red blood cells,

W is the volumetric percentage of water in the red blood cells,

$Hct_i$  is the hematocrit level of the red blood cells before cryopreservation,

$V_g$  is the volume of cryopreservation solution that has already been added to the red blood cells prior to the current flow rate calculation,

$O_i$  is the osmolarity of the red blood cells before cryopreservation, and

$O_g$  is the osmolarity of the cryopreservation solution.

16. The method of claim 15 further comprising the step of agitating the blood component as the cryopreservation solution is being delivered thereto.

17. An apparatus for diluting a thawed, cryopreserved blood component with a volume of a dilution solution that exposes the blood component to a risk of osmolarity shock, in preparation for recovery of the blood component, the apparatus comprising: means for coupling the dilution solution to the blood component;

at least one variable-speed pump disposed in the coupling means, operation of the at least one pump at a given speed defining a respective flow rate of dilution solution to the blood component; and

a controller operably coupled to the at least one pump so as to control the rate at which dilution solution is delivered to the blood component; the controller configured to dynamically adjust the flow rate of the dilution solution to reduce the risk of osmolarity shock to the blood component.

18. The apparatus of claim 17 wherein the controller dynamically adjusts the dilution solution flow rate so as to maintain a linear decrease of blood component osmolarity.

19. The apparatus of claim 18 wherein the blood component is red blood cells and the controller is configured to adjust the speed of the at least one pump so that the flow rate of dilution solution is substantially given by the following equation:

$$K_D [V_i * (W * Hct_i/100) + V_s]^2 / [V_i * (W * Hct_i/100) * (O_i - O_s)]$$

where,

$K_D$  is the desired osmolarity rate decrease,

$V_i$  is the volume of the thawed red blood cells after dilution with the hypertonic solution,

$W$  is the volumetric percentage of water in the red blood cells,

10 Hct<sub>i</sub> is the hematocrit level of the thawed red blood cells after dilution with the  
11 hypertonic solution,

12 V<sub>s</sub> is the volume of washing solution that has already been delivered to the  
13 thawed red blood cells,

14 O<sub>i</sub> is the osmolarity of the thawed red blood cells after dilution with the  
15 hypertonic solution, and

16 O<sub>s</sub> is the osmolarity of the washing solution.

1 20. The apparatus of claim 19 wherein the controller is configured to initially  
2 adjust the speed of the at least one pump so that the initial flow rate of dilution solution  
3 is substantially satisfied by the following equation:

$$4 \quad K_D * V_i * (W * Hct_i / 100) / (O_i - O_s).$$

1 21. The apparatus of claim 20 further comprising a shaker platform for agitating  
2 the blood component as the dilution solution is being delivered thereto.

1 22. A method for diluting a thawed, cryopreserved blood component with a  
2 volume of a dilution solution that exposes the blood component to a risk of osmolarity  
3 shock, in preparation for recovery of the blood component, the method comprising the  
4 steps of:

5 coupling the volume of dilution solution to the thawed blood component by  
 6 means of at least one variable-speed pump such that operation of the pump at a given  
 7 speed defines a respective flow rate of dilution solution to the blood component;  
 8 dynamically adjusting the flow rate of the dilution solution, by periodically  
 9 changing the speed of the at least one pump, to reduce the risk of osmolarity shock to  
 10 the thawed blood component.

1 23. The method of claim 22 further comprising the step of diluting the thawed  
 2 blood component with a volume of a hypertonic solution prior to delivering the dilution  
 3 solution, the hypertonic solution having an osmolarity that is substantially similar to the  
 4 osmolarity of the blood component.

1 24. The method of claim 23 wherein the blood component is red blood cells and  
 2 the step of dynamically adjusting comprises the step of changing the speed of the at  
 3 least one pump so that the flow rate of dilution solution is substantially given by the  
 4 following equation:

$$5 \quad K_D [V_i * (W * Hct_i/100) + V_s]^2 / [V_i * (W * Hct_i/100) * (O_i - O_s)]$$

6 where,

7  $K_D$  is the desired osmolarity rate decrease,

8  $V_i$  is the volume of the thawed red blood cells after dilution with the hypertonic  
 9 solution,

10  $W$  is the volumetric percentage of water in the red blood cells,



11 Hct<sub>i</sub> is the hematocrit level of the thawed red blood cells after dilution with the  
12 hypertonic solution,

13 V<sub>s</sub> is the volume of washing solution that has already been delivered to the  
14 thawed red blood cells,

15 O<sub>i</sub> is the osmolarity of the thawed red blood cells after dilution with the  
16 hypertonic solution, and

17 O<sub>s</sub> is the osmolarity of the washing solution.

1 25. The method of claim 24 wherein the step of dynamically adjusting further  
2 comprises initially adjusting the speed of the at least one pump so that the initial flow  
3 rate of dilution solution is substantially given by the following equation:

$$4 \quad K_D * V_i * (W * Hct_i / 100) / (O_i - O_s).$$

1 26. The method of claim 25 further comprising the step of agitating the thawed  
2 blood component as the dilution solution is being delivered thereto.

1 27. An apparatus for preparing a blood component for cryopreservation by  
2 mixing the blood component with a volume of cryopreservation solution that exposes  
3 the blood component to a risk of osmolarity shock, and for diluting a thawed,  
4 cryopreserved blood component with a volume of a dilution solution that also exposes  
5 the blood component to a risk of osmolarity shock, in preparation for recovery of the  
6 blood component, the apparatus comprising:

7 at least one variable-speed pump coupled to the blood component and selectively  
8 coupled to either the volume of cryopreservation solution or the volume of dilution  
9 solution, operation of the pump at a given speed defining a respective flow rate of  
10 either cryopreservation solution or dilution solution to the blood component; and  
11 a controller operably coupled to the at least one pump so as to control the rate at  
12 which either cryopreservation solution or dilution solution is delivered to the blood  
13 component, the controller configured to dynamically adjust the flow rate of either the  
14 cryopreservation solution or the dilution solution to reduce the risk of osmolarity shock  
15 to the blood component.